A 1 Megawatt Multi-Stage Proton Accumulator

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Concept

- After the collider program concludes, the present antiproton production complex can be converted into a multi-stage proton accumulator for injection into the Main Injector.
  - Accumulator -> Momentum Stacker
  - Recycler -> Box Car Stacker
- The proposal needs to have the following important features
  - It must be inexpensive (< $15M or so)
  - It must be completed quickly (before 2010)
  - It should not shutoff the collider complex or the present neutrino program for an extended period of time.
- These goals can be accomplished only if:
  - It uses the present Fermilab infrastructure (tunnel enclosures, service buildings, power, utilities, etc.)
  - The project is staged

Project Staging

- Because the concept uses existing infrastructure the performance can be broken into stages
- Project staging has the important benefit of providing
  - a fraction of the total performance
  - at a fraction of the total cost
- The schedule for each stage is driven by physics need and funding availability
- Each stage is based on standard accelerator technology and accelerator parameters that are currently achievable.

Project Stages

- Present
  - Present Booster
  - 5-6 Booster batches loaded consecutively in the Main Injector (2-2.5 sec. cycle time)
- Stage 1
  - Proton Plan Booster with increased aperture
  - 9-12 Booster batches loaded consecutively and then slip-stacked in the Main Injector (2.2 sec. cycle time)
- Stage 2
  - Proton Plan Booster with increased aperture
  - 12 Booster batches slip-stacked in the Recycler
  - Single turn load in the Main Injector (1.5 sec. cycle time)
- Stage 3
  - Proton Plan Booster with increased aperture but lower batch intensity
  - 4 Booster batches momentum stacked in the Accumulator
  - 6 Accumulator batches box-car stacked in the Recycler
  - Single turn load in the Main Injector (1.6 sec. cycle time)

Stage Intensity Parameters

Parameter	Present	Stage 1	Stage 2	Stage 3	
Booster Flux	6.38	13.53	13.54	21.59	$\times 10^{16}$/Hr
Collider Flux	1.09	1.41	0.00	0.00	$\times 10^{16}$/Hr
120 GeV Proton Flux	3.21	7.05	13.54	21.59	$\times 10^{16}$/Hr
120 GeV Beam Power	162	367	704	1140	kW
8 GeV BNB* Flux	2.08	5.07	0.00	0.00	$\times 10^{16}$/Hr

Parameter	Present	Stage 1	Stage 2	Stage 3	
Booster Extraction Intensity	4.43	4.70	4.70	4.00	$\times 10^{12}$
Booster Rep. Rate	4	8	8	15	Hz
Booster Beam Power Lost	440	440	440	440	Watts
Booster Notch Bunches	7	4	4	0	

Trade off intensity for Rep. Rate

No Booster to Accumulator Phase alignment

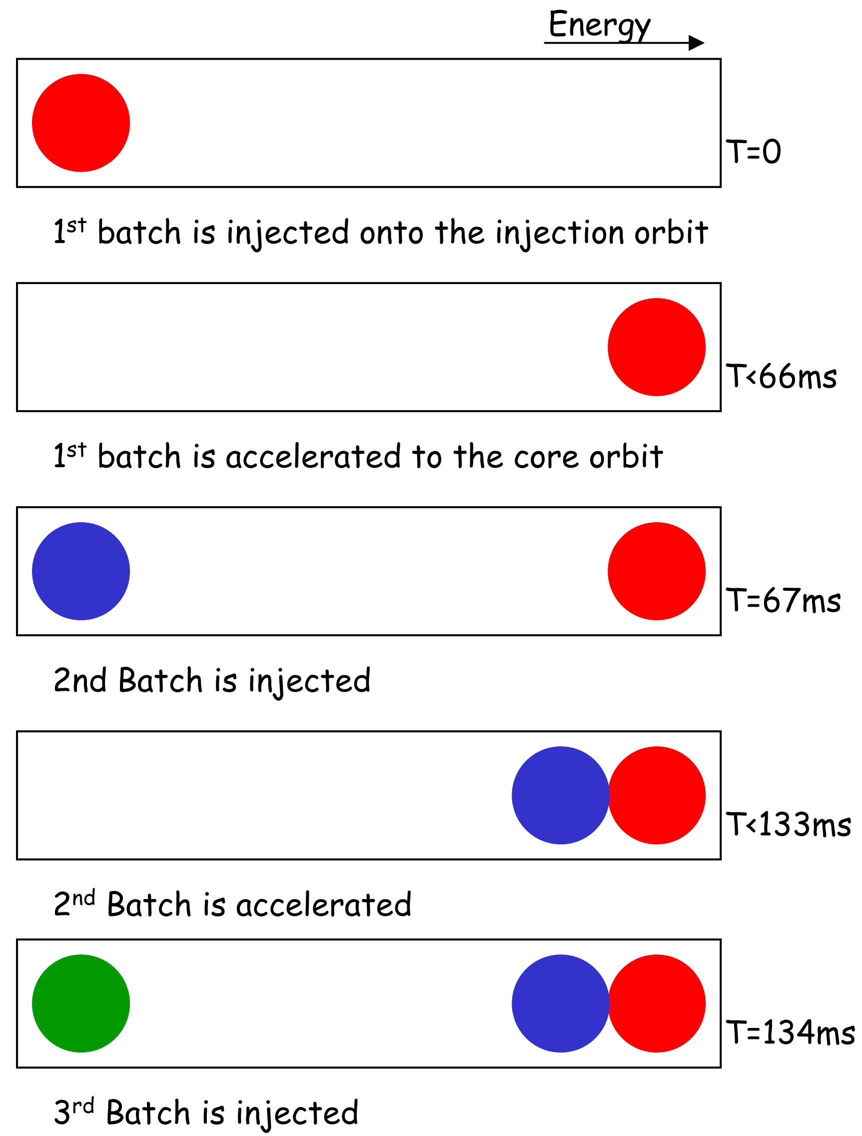
*Booster Neutrino Beam

Stage 3 – A 1MW Multi-Stage Proton Accumulator

- Concept is based on proton momentum stacking in the present antiproton Accumulator
  - Using the Accumulator as a proton accumulator **reduces the peak intensity requirement at injection into the Booster**
  - Results in a smaller required aperture for the Booster
    - Smaller space charge tune shift
    - Reduced requirements on acceleration efficiency

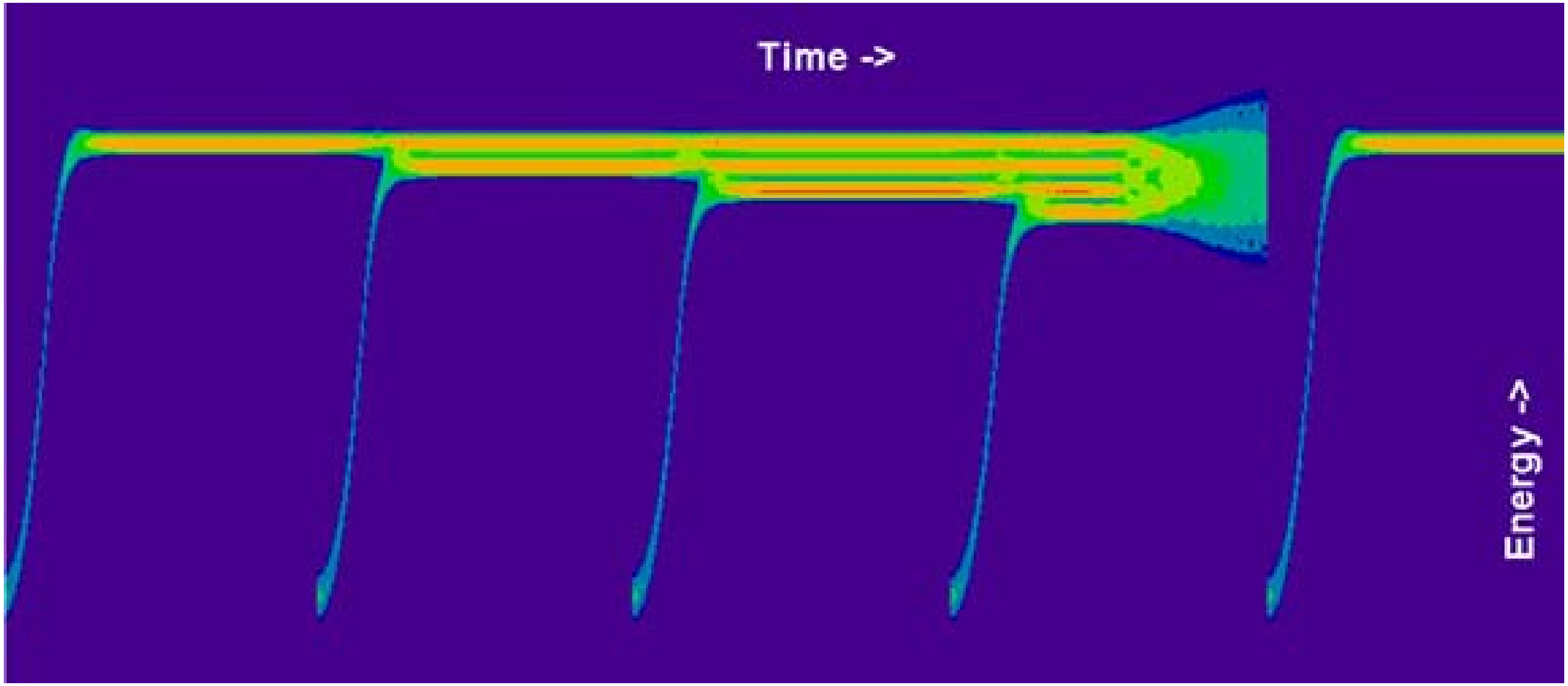
Mechanics of Momentum Stacking

- Inject in a newly accelerated Booster batch every 67 mS onto the low momentum orbit of the Accumulator
- The freshly injected batch is accelerated towards the core orbit where it is merged and debunched into the core orbit
- Momentum stack 3-4 Booster batches



Momentum Stacking Simulation

Output longitudinal emittance = 84 * 0.38 eV-sec

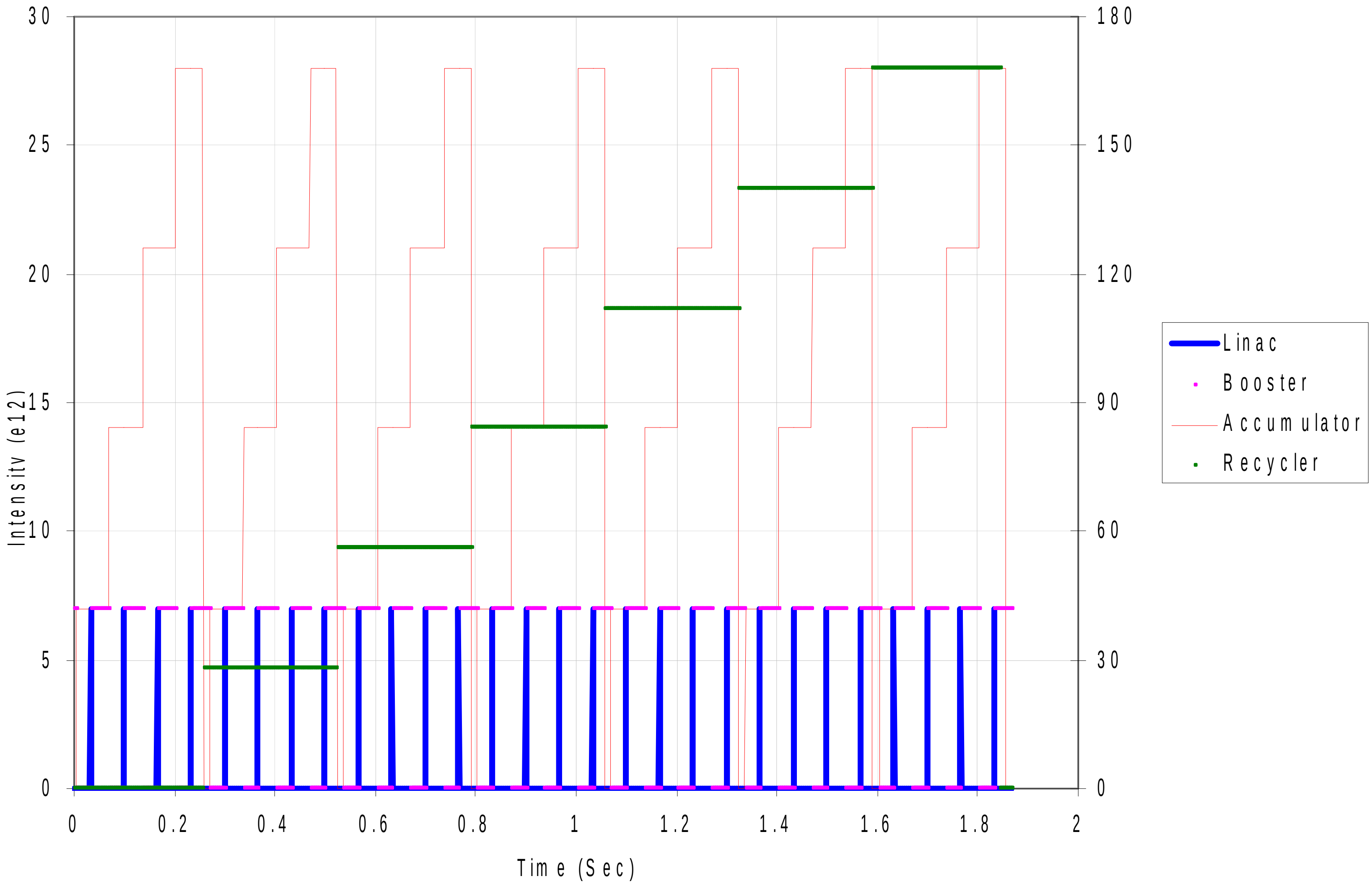


Input longitudinal emittance = 84 * 0.08 eV-sec

Multi-Stage Proton Accumulator Scenario

- Momentum stack in the Accumulator
  - Inject in a newly accelerated Booster batch every 67 mS onto the high momentum orbit of the Accumulator
  - Decelerate new batch towards core orbit and merge with existing beam
  - Momentum stack 4 Booster batches
  - Extract a single Accumulator batch
    - Every 270 mS
    - At an intensity of 4x a single Booster batch
- Box Car Stack in the Recycler
  - Load in a new Accumulator batch every 270mS
  - Place six Accumulator batches sequentially around the Recycler
- Load the Main Injector in a single turn

Multi-stage Proton Accumulator Production Cycle

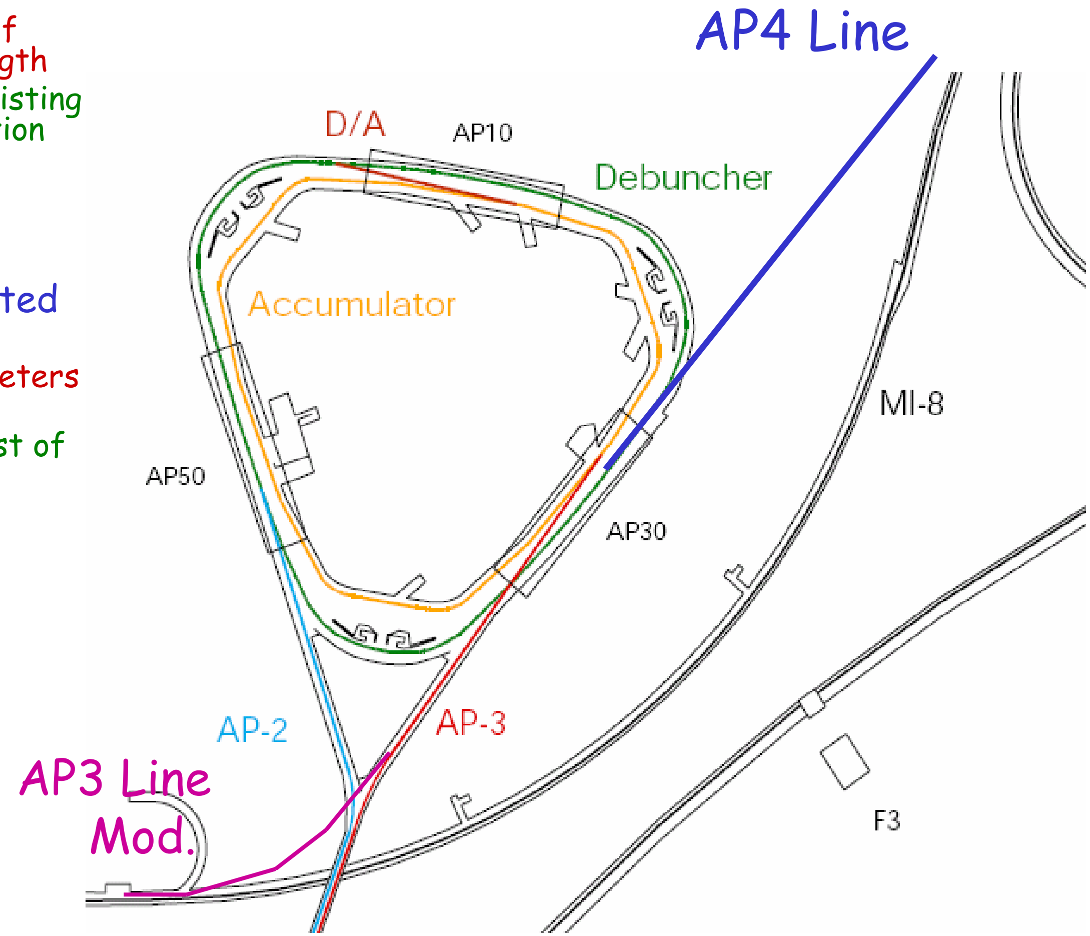


Advantages of Momentum Stacking

- The Accumulator was designed for momentum stacking
  - Large momentum aperture ~ 84 x 2.8 eV-Sec
  - Injection kickers are located in 9m of dispersion
  - Injection kickers do not affect core beam
- Transient Beam Loading
  - Slip stacking or barrier bucket stacking requires manipulating intense beams with low RF voltages in a mostly empty circumference
  - In momentum stacking, the circumference is always uniformly loaded
- Speed of process
  - Injected beam can be decelerated quickly towards the core beam
- Longitudinal emittance dilution
  - The core beam can be debunched during stacking process reducing the amount of "white spaces"
- Cogging in the Booster
  - Prior to injection into the Accumulator, the injection orbit of the Accumulator is empty
  - The Accumulator injection system can be phase-locked to the Booster which eliminates the need for cogging in the Booster
  - The Booster notch can be made in the Linac

Modifications to the Present Complex - Transfer Lines

- AP4 Line
  - The Booster is connected to the Accumulator via a re-built AP4 Line
  - The new AP4 line is about 240 meters in length
    - Compared to the 600 MeV line of PD2* which is 250 meters in length
      - Use Magnets from the existing AP2 line for 8 GeV operation
      - 600 MeV magnets 1M$
      - Civil Construction 1.8 M$
- AP3 Line
  - The AP3 line needs to be connected to the MI-8 line
    - The modification is about 100 meters in length
      - Use magnets from the rest of existing AP3 line
      - Civil Construction 1.4 M$



*PD2: Synchrotron option of the Proton Driver Design Report II

Modifications to the Present Complex - RF systems

- After 4 booster batches have been momentum stacked in the Accumulator, the beam would be transferred to the Recycler.
  - 7.5 MHz MHz synchronous transfer
    - New system
    - Need 80kV/Turn for a 4.2 eV-sec bucket
  - Accumulator phase ALIGNED to the Recycler
- The Accumulator is 1/7 of the Recycler's circumference
- Boxcar stack six of the Accumulator batches leaving 1/7 of the Recycler ring for an abort gap.
- After 6 Accumulator batches have been stacked into the Recycler debunch 7.5 MHz beam in >80mS
- Re-capture in 53 MHz buckets for acceleration.
  - Need 500 kV for 0.6 eV-sec
  - Re-use three Tevatron RF cavities

Stage 3 Cost Estimate in k$

Description	Cost
Linac Notching	100
Booster Extraction Upgrade	1,000
AP4 Line Civil	1,800
AP4 Tie In & Installation	500
AP3 Modification Civil	1,400
AP3 Tie In & Installation	500
Accumulator Shielding	3,000
Accumulator Kickers	1,000
Accumulator 53 MHz RF	400
Accumulator 7.5 MHz RF	400
Accumulator Instrumentation	200
Recycler 7.5 MHz RF	1,000
Recycler 53 MHz Installation	300
Recycler Instrumentation	200
Total	11,800

Summary

- The present antiproton production complex can be converted into a multi-stage proton accumulator that supplies enough protons for a 1.1 MW 120 GeV beam for a cost of about $12M
- Because the concept uses existing infrastructure the performance can be broken into stages
  - Project staging has the important benefit of providing
    - a fraction of the total performance
    - at a fraction of the total cost
  - The schedule for each stage is driven by physics need and funding availability
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